CALFED Science Program

Temperature Management and Modeling Workshop in support of an Operations Criteria and Plan Biological Assessment and Biological Opinion

April 1, 2008

Report Prepared for

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by a

Science Advisory Panel

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Workshop Format

On April 1, 2008, the CALFED Science Program held a workshop to provide a forum for discussing issues related to modeling and managing temperature in the upper Sacramento River and associated Central Valley tributaries. Temperature modeling will be pursued in support of an Operations Criteria and Plan (OCAP) Biological Assessment (BA) by the U.S. Bureau of Reclamation/California Department of Water Resources for the Central Valley and Sate Water Projects. Ultimately, the National Marine Fisheries Service (NMFS) will rely on the biological assessment as it develops a Biological Opinion (BO) to cover the OCAP's activities. Although not a formal review, the workshop facilitated discussion of pertinent issues and an evaluation of available tools and management alternatives, while providing independent feedback to agencies regarding temperature management in the upper Sacramento River and associated Central Valley tributaries.

The workshop included a series of presentations by NMFS and Reclamation staff addressing such topics as background information on existing agency objectives and responsibilities, recovery objectives, temperature modeling capabilities, and possible alternatives to current modeling and management approaches. In addition, three speakers presented examples of model approaches being used elsewhere in California and new approaches being developed for the Central Valley. The workshop focused strictly on those areas affected by efforts to manage temperature and flow to improve the spawning habitat of anadromous fish and benefit such species during their early life stages. Although presentations focused on the upper Sacramento River, the area of consideration included reaches of the Sacramento and San Joaquin rivers and tributaries where Reclamation facilities exist. In-Delta flows and temperatures were not considered.

The Advisor Panel

The CALFED Science Program convened an independent panel of subject matter experts to participate in the workshop and provide a summary report to the CALFED Lead Scientist.

The panel comprised the following independent experts:

- Dr. Tommy Williams (facilitator), NMFS Southwest Fisheries Science Center;
- Dr. Michael Deas, Watercourse Engineering;
- Dr. Peter Goodwin, University of Idaho, Boise;
- Dr. Steve Lindley, NMFS Southwest Fisheries Science Center; and
- Dr. Christa Woodley, University of California, Davis

In advance of the meeting, panel members were asked to consider the following potential questions and topics for consideration during the workshop:

- The operational paradigm to meet in-stream temperature objectives for salmonids is based on coldwater pool management (e.g., using the Shasta Dam Temperature Control Device on the Sacramento River, and Folsom Dam Shutters and release-water blending on the American River). Do the current modeling assumptions provide adequate information on the performance of this paradigm to meet fish temperature needs?

- Is reservoir carry-over storage from the end of summer into the wet season an important indicator of the operational ability to meet in-stream temperature needs for fish in the following year? Do other modeling tools provide better predictions and/or offer more informative outcomes?

- Are the objectives related to temperature management consistent with the system's capabilities? How have the Central Valley Project's capabilities evolved over time?

- How well have the changes in the 2008 model runs responded to the temperature-related concerns identified in the reviews of the 2004 OCAP Biological Opinion?

- Can existing models be effectively adapted for use given our emerging understanding of flow and temperature management in local reservoir/river systems? If not, are there viable, proven alternatives that can be deployed immediately to help clarify these relationships and better inform the parties in this consultation?

- If other modeling tools are available, how might they be used to improve the current analysis and guide future management actions? Should other models be developed?

- Do the climate-change scenarios represent a reasonable range of future conditions and provide sufficient information to assess potential operational effects? Is uncertainty adequately addressed?

- Are there improvements to the protective standards that NMFS uses for listed salmonids (winter-run Chinook, spring-run Chinook, Steelhead) that could work better with existing or anticipated operational models?

Panel members were tasked with providing a written report synthesizing the workshop's discussions and their impressions regarding modeling approaches and making recommendations for their use. The panel's recommendations will be considered by Reclamation and the California Department of Water Resources as they develop and finalize the OCAP for the Central Valley and State Water Projects, as well as NMFS as it develops a BO regarding actions within the OCAP for managing upstream flow and temperature.

Appendix A includes a list of workshop materials provided to the panel for review. All presentations from the workshop are listed in Appendix B and included in electronic format here:
(http://www.science.calwater.ca.gov/events/workshops/workshop_tmm.html).

Panel Workshop Summary

The review panel appreciated the quality of the presentations and the frank discussion regarding the current state of salmon recovery approaches, the upper Sacramento River's thermal regime, gaps in monitoring programs and current knowledge, alternative methods of project operations, and temperature models. The workshop's structure provided a balance between the state of the science, challenges faced by Reclamation and NMFS in managing the system, and expectations of regulatory agencies when fulfilling their objectives.

Because Reclamation's draft Biological Assessment (BA) is scheduled to be submitted to NMFS almost concurrent to the release of this document, the Panel understands that it may not be feasible to fully consider or implement the following recommendations. However, an opportunity to address issues herein may arise before the NMFS issues its Biological Opinion (BO) on OCAP. The BO may identify certain recommended actions as reasonable and prudent for addressing in the future. Furthermore, the history of this large, complex project, together with the fact that consultation on endangered species has occurred multiple times since 1990 (see Table 1), recurring consultations are anticipated. Such consultations would afford additional opportunities for fine-tuning the Panel's recommendations. Finally, while this workshop was initiated to address the OCAP's current needs, related projects on streams not part of either the Central Valley Project of the State Water Project could benefit from the workshop's recommendations.

The panel chose to focus on two main topics: information gaps and areas where additional information would be useful in the future to Reclamation and NMFS. This focus included identifying new approaches and technologies that will assist in managing species of concern and can inform future endangered species consultations. Activities related to the BA and BO offer an opportunity to use new and emerging technologies capable of providing a more detailed understanding of river thermal regimes – particularly for management operations and short-term planning. The panel recognizes that taking advantage of this opportunity will build on the strong knowledge base within the agencies.

Table 1. NOAA Fisheries, ESA section 7 Consultation History (1991-2004) for the Project (NMFS, 2004)

Date	Species	Consultation Description
2/26/91	WR	NOAA Fisheries requests consultation on Reclamation's CVP operations and plans
2/14/92	WR	Initial biological opinion addressing effects of CVP operations (J)
2/12/93	WR	Long-term OCAP biological opinion addressing effects of both CVP and SWP operations (J)
8/02/93	WR	1st amendment on Red Bluff Diversion Dam (RBDD) Pilot Pumping Program
10/06/93	WR	2nd amendment changed date of RBDD screening requirement
12/30/94	WR	3rd amendment incorporated new Bay-Delta Standards
5/17/95	WR	4th amendment changed Delta flow criteria and increased take limit
8/18/95	WR	5th amendment temporarily changed temperature compliance point
3/27/00	SR, Sthd	1999-2000 Interim OCAP BO (*i.e.*, new species listed)
8/28/00	all	CALFED Bay-Delta Program, Record of Decision (ROD)
10/12/00	all	Trinity River Mainstem Fishery Restoration biological opinion
11/14/00	all	Central Valley Project Improvement Act (CVPIA) programmatic BO
5/08/01	SR, Sthd	2001-2002 Interim OCAP BO
9/20/02	SR, Sthd	2002-2004 Interim OCAP BO, amends and extends
6/03	all	Preliminary working draft, Long-term OCAP BA
2/27/04	SR, Sthd	2004-2006 Supplemental interim OCAP BO

WR: winter-run Chinook salmon; SR: spring-run Chinook salmon; Sthd: steelhead

Specific Panel Comments

Panel comments have been grouped into three broad categories:

- temperature modeling and thermal considerations,
- biological considerations, and
- operations and planning.

Of course, these categories contain some overlap.

Temperature Modeling and Thermal Considerations

Comment 1: Adopt an analytical framework for modeling flow and temperature as a way to characterize more effectively the complex river and reservoir systems and their influences on fish life cycles.

The upper Sacramento River is a complex hydrologic ecosystem that is also heavily managed. Much of the aquatic ecosystem's physical and biological diversity has been lost during the past two centuries. Decisions made for one objective (temperature maintenance, for example) in one river reach can affect other reaches or other objectives. Therefore, effective integration of models and synthesis of available information are needed to provide a transparent framework for understanding the extent to which the system can be controlled.

Workshop presentations did not indicate that an analytical framework characterizing the various components of the river system(s) in question had been implemented for the current BA or will be included in the future BO. However, Lichatowich et al. (2005) previously identified the utility of using a conceptual framework and an analytical framework in characterizing the system's various components and quantifying important processes. As stated in Lichatowich et al., "[T]he basis for the analytical framework is a clearly articulated conceptual framework and a life cycle approach. The analytical framework itself consists of the models, analytical tools, and assumptions used in the assessment, and how these models and tools relate to each other in terms of shared information and overlapping assumptions" (page 17). Furthermore, such a framework can assist in quantifying uncertainty associated with information transferred from one model to another (e.g., second generation data). The panel concurs with Lichatowich et al., and encourages the parties to consider an analytical framework for modeling flow and temperature as a way to characterize more effectively the complex river and reservoir systems and their influences on fish life cycles.

Comment 2: Adopt the latest technology in flow and temperature modeling that will resolve some of the problems identified in previous reviews of the OCAP BO. This recommendation includes adopting models with smaller time-steps to better assess biological effects.

Three modeling time steps were identified: a monthly time step planning model for reservoir and river reaches; a daily time step model for intermediate planning (e.g., annual or seasonal operations); and a sub-daily model (6-hour time step) for short-term operations on the order of days. Such a suite of models can form a powerful nested tool set for planning and management activities in a large, complex system.

Although modeling at multiple time scales provides useful information at a variety of resolutions, each model's specific objectives were not identified. For example, the panel is uncertain if all models are available for all river reaches and are applied uniformly across temporal and spatial resolutions. Discussions focused on the upper Sacramento River, and the panel is unclear if temporal and spatial assumptions appropriate for this reach are applicable to other river reaches or tributaries (e.g., American or Stanislaus rivers). The panel recommends that spatial and temporal information relevant to each system be identified in the BA to allow appropriate interpretation of the results. The panel also agrees with Reclamation's strategy of using the models to understand the overall thermal regime rather than attempting to include microhabitat thermal refugia in the model domain. Although ecologically important, these key thermal refugia associated with cold water springs and floodplain channels are best linked to the BA by integrating modeling and field research efforts rather than combining models *per se*.

Panel members also identified a need for Reclamation to consider more recent modeling techniques. The monthly planning models Reclamation uses were developed more than 30 years ago (though subsequent refinements have been made). The HEC-5Q model was developed in the 1980s and is currently not supported by the Army Corps of Engineers. Workshop presentations identified a few of the more recent modeling tools that have been employed or are under development. To resolve some of the problems identified in previous reviews of the OCAP BO, the panel recommends that Reclamation adopt the latest technology in flow and temperature modeling (see also Comment 4, below). This action includes adopting models with smaller time-steps to better assess biological effects, and will assist with "near real-time" operations during critical summer periods.

Comment 3: Disaggregating temperature characterizations into daily and sub-daily time steps may be important as input into future models that rely on this information.

Workshop presentations and discussions suggested that many analyses in the biological assessment are based on second generation data derived from monthly time step operations models such as CALSIM. In the limited time available, details were not presented on the methods used for disaggregating monthly flow data into daily and sub-daily time steps for input to the temperature models. Nonetheless, the panel feels that disaggregating temperature characterizations into daily and sub-daily time steps may be important as input into future models that rely on this information. Methodologies for disaggregating temperature input data must be presented in the BA documentation or should be available upon request.

Aggregating data can directly affect analyses. For example, average temperatures and instantaneous temperatures have different biological implications. Using mean monthly or daily temperatures can mask high frequency fluctuations that may impact biota (e.g., short-term, sub-lethal water temperatures). A strategy for understanding these temperature fluctuations spatially and temporally should be developed as part of the BA or BO. Lichatowich et al (2005) identified an approach for comparing measured sub-daily data and daily or monthly model results to estimate the magnitude of variability lost through either aggregating to a longer time step or simulating at a longer time step.

Comment 4: Collect temperature and flow data from major tributary creeks, and detailed vertical profiles from within Shasta Reservoir.

The workshop identified clear data needs to support temperature modeling and system management. These include:

- Major tributary temperatures below Keswick Dam (Clear, Cow, Battle, and Cottonwood creeks). Hourly data could readily be collected at these locations to assist in real-time operations and construct long-term records to identify potential tributary–mainstem relationships that would enable more effective seasonal cold water management. Temperature data also should be collected for tributaries and inflows below mainstem facilities on other rivers. During discussions at the workshop, participants suggested that these tributaries are currently monitored for flow. However, if they are not, the panel also recommends adding appropriate instrumentation to collect flow data.
- The panel felt that vertical temperature profiles in Shasta Reservoir could be collected more frequently than monthly or twice-monthly. Doing so would improve understanding of the reservoir's internal thermal structure and help optimize the management of cold water. The reservoir exhibits inter- and intra-annual temperature variability on relatively short time scales (e.g., weeks to months), and probably also experiences shorter duration variability in response to inflows of varying density, wind mixing, Temperature Control Device (TCD) operations, and other factors. The current frequency and duration of observations are insufficient to capture many of these processes. Information should be collected at an intensity and duration sufficient to capture inter- and intra-annual variability in hydrology, meteorology, operations, and storage conditions. However, the duration of such activities would need to be determined (e.g., hourly or daily for 20 years? 40 years? Longer?). Furthermore, profiles at additional intervals upstream of the dam could assist in defining the influence of withdrawals through the TCD or other outlets, as well as inform system operators of potential impacts of tributary inputs on the reservoir's thermal structure.
- During workshop discussions, the process by which water temperature is monitored in reaches below mainstem dams was unclear. To control temperature effectively in downstream river reaches, real-time arrays of temperature devices should be deployed at appropriate intervals to monitor conditions and the efficacy of management actions. In time, such monitoring would provide valuable data to system operators during real-time management, while compiling a history of system responses under variable conditions that would assist seasonal planning exercises.
- Tributary inflows to major reservoirs were also identified as an important data gap. Tributary inflow and temperature play critical roles in determining a reservoir's ultimate volume of cold water and its thermal structure. Quantifying inflows may help managers identify the likely range of conditions and plan a reservoir's operation in a given year. Tributary monitoring coupled with in-reservoir profiles could inform management strategies, particularly under lower storage conditions where cold water volumes may be limited and efficient management is required.

- The panel was concerned by the “rule of thumb” that uses air temperature in Redding, California, as a surrogate for water temperature. In general, air temperatures are a poor predictor of stream temperature at short time scales. A more detailed statistical analysis could be developed that includes solar radiation—the dominant heating term in heat exchange at the air–water interface—and other parameters. This analysis would help identify the most important parameters in the heat balance equation and perhaps also identify the value of additional meteorological data monitoring. Additional meteorological monitoring may include a series of stations identifying conditions at the reservoir as well as conditions downstream. These data would be used to interpret observed temperatures in the river and reservoir and to distinguish the operational thermal response for a range of meteorological conditions.

While providing information for management decisions, monitoring also is used to continue model development. Important aspects of an effective monitoring program involve regularly assessing emerging technologies, assimilating additional data into existing models, and pursuing a modeling strategy that takes advantage of the continually growing data sets. These facets improve the predictive capability of the next generation of models. For example, the reservoir tributary inflow monitoring program would be a logical precursor to development of an upstream (above the reservoir) watershed model that would improve the prediction of inflow timing, quantity, and temperature, to assist in managing cold water supplies. A large body of literature on monitoring equipment and methods exists, and information on program implementation is readily available from one of the many manufacturers or vendors. (see, for example: Gilvear, 2006; Hofmann and Gaines, 2008).

Comment 5: Assess the value of more precise estimates of tributary inflow and the value of continuous real-time recording of the thermal structure in Shasta and other reservoirs in the system.

Reclamation meets temperature objectives in the upper Sacramento River via the operation of Shasta Dam (and reservoirs on other river systems, e.g., Trinity and Stanislaus rivers). Conditions are evaluated throughout the critical summer period according to a single vertical temperature profile taken approximately once or twice a month. At the start of the year, decisions on how to operate Shasta are based on the available volume of cold water (defined as $<52^{o}$F (10.6^{o}C)) that is impounded, with a goal of fully using the cold water pool by season’s end.

In dry years, the relation between total stored volume and cold water storage shows less variability (see Figure 1). However, in wet years prediction is more problematic: In some years, nearly all the storage volume is below 52^{o}F (10.6^{o}C), while in other wet years cold water comprises only about one-third of the volume. The workshop discussion concerning the variability of different years, the effect of carryover storage, and the difficulty in forecasting the volume of cold water storage early in a given year highlighted some of the difficulties faced by Reclamation and agency staff managing the cold water pool during summer periods.

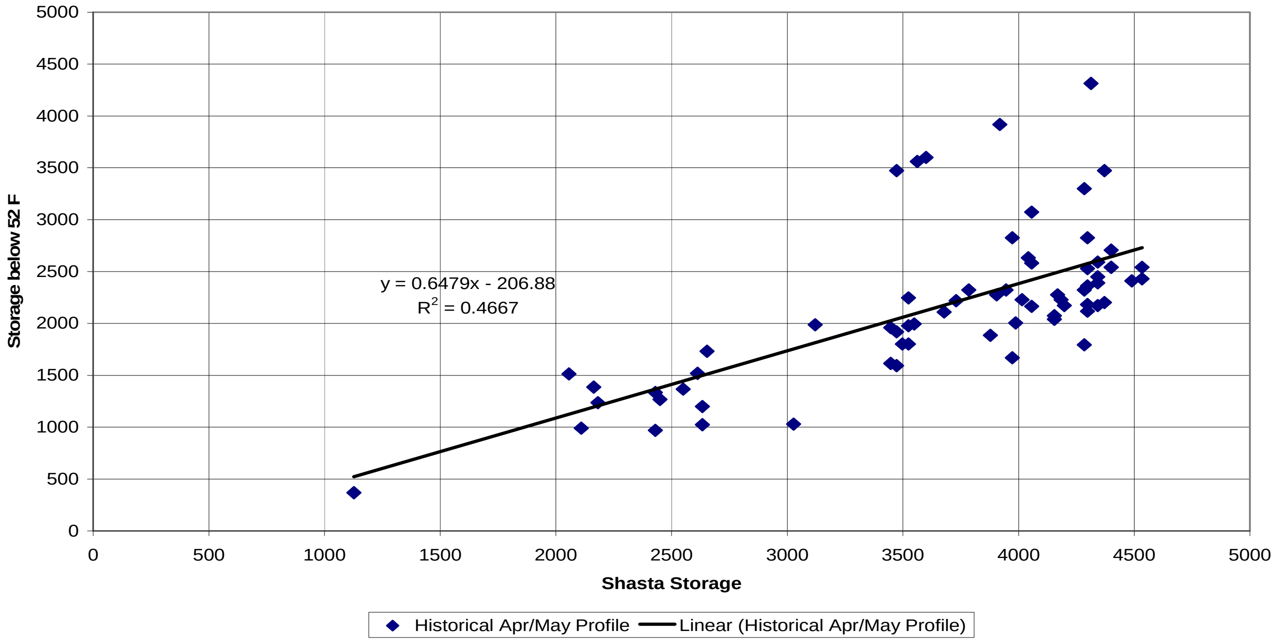

Figure 1. Historical Apr/May Shasta Coldwater Profile 1972-2002 (U.S. Bureau of Reclamation)

To improve predictability in terms of managing cold water, the panel recommends that Reclamation assess the value of more precise estimates of tributary inflow and the value of continuous real-time recording of the thermal structure in Shasta and other reservoirs in the system. Existing reservoir and river models can be used to estimate effects on temperature from releases if a seiche affects the TCD performance. The models could also be used to estimate variability in temperature releases and the benefits of more complex operational rules that might conserve the coldest water for the most critical periods.

Commensurate with the recommendation to refine operational rules based on more frequent or real-time monitoring, the panel recommends that Reclamation investigate emerging technologies for monitoring temperature, turbidity, and flow. A similar field evaluation is under way by Reclamation’s Snake River Area Office (Allyn Meuleman, Activity Manager). This evaluation includes costs and available technologies. An exchange of experiences could benefit the studies of both the upper Sacramento and Snake rivers.

Comment 6: Include alternative means of alleviating thermal stress such as floodplain restoration, reducing thermal gain from tributaries, and improving fish passage to cooler tributaries.

This workshop mostly focused on reservoir operation as the management tool for addressing temperature issues in the upper Sacramento River. An important alternative discussion should include other means of alleviating thermal stress, such as restoring floodplains, reducing thermal gain from tributaries, and improving fish passage to cooler tributaries. The panel encourages an evaluation of a diverse range of possible management alternatives to facilitate species recovery.

Biological Considerations

Comment 7: Identify specific biological impacts to salmonids of an altered thermal regime using a life cycle model that includes associated conceptual links to habitats and cumulative stressors.

Relatively little time was spent at the workshop evaluating how altered thermal regimes affect salmonids. However, this topic will be a critical element of the BA and BO, so the panel offers some guidance on this issue. Reviews of the previous BO noted the need for a conceptual model organized around the salmon life cycle to guide thinking and analysis (Lichatowich et al. 2005, Lindley et al. 2006). The analysis of the biological effects should consider: 1) all of the impacts that operations have on all relevant salmonid habitat attributes (e.g., temperature and flow regime, obviously, but also geomorphic effects on physical habitat, and distribution and abundance of salmon predators and prey); 2) the intersection between these habitat effects and life histories of focal species; 3) the direction and magnitude of each impact, and; 4) cumulative effects over all life stages on the fitness of individuals and the abundance, productivity, spatial structure, and diversity of populations.

Comment 8: Improve efforts at monitoring spring-run Chinook salmon and Sacramento River steelhead.

Because the predicted impacts of project operations will be uncertain, monitoring is needed to assess whether impacts exceed expectations. Articulated conceptual models and impact assessments will identify key life stages, places, and species where impacts are potentially significant, and note where monitoring should be directed. Although existing monitoring for winter Chinook salmon may be adequate, workshop participants expressed greater concern about monitoring of spring Chinook salmon. In addition to providing abundant information on spatial and temporal patterns, carcass surveys can provide an indication of pre-spawning mortality. Meanwhile, juvenile emigration monitoring at Red Bluff may be able to detect low levels of survival between egg and fry stages. Similar monitoring is needed for other species. Monitoring for steelhead is especially inadequate, and concerns have been expressed that life history tactics of *O. mykiss* on the upper Sacramento River have shifted from anadromy to residency, perhaps due to disruption of migratory cues or creation of conditions that elevate the fitness of resident individuals relative to anadromous individuals (Williams et al. 2007).

Comment 9: Effectively incorporate “stress” into models of fish mortality.

The following comment discusses three general challenges associated with modeling fish mortality: 1) stressor matrix models, 2) fixed thermal limits for salmonids, and 3) use of temperature in mortality models.

Stressor Matrix Models

The workshop presentations and their associated discussions suggested that the techniques used to assess biological monitoring and modeling employ the best available data. The panel recognized that neither group were given adequate time to fully detail their modeling methods that are being incorporated into the current BA/BO. With this in mind, we emphasize that agencies must consider “stress” and its relevance to fish (i.e., effects, intensity of stressors, and temporal scales). Clearly articulating what is meant by “stress” and “stressors” on the species of interest will assist agencies with short- and long-term planning as well as project implementation. Simple stressor matrix models can indicate where research is needed to better understand the biology of regionally important fish. However, matrix models tend to be overly general and qualitative as opposed to the quantitative model proposed by NMFS. Another difficulty the panel found with the matrix models detailed during the workshop was that stressor descriptions, weightings, and impacts were unclear, undocumented, and/or unsubstantiated.

The stress response of fish varies with the intensity and/or duration of the stressor. Considerable work has been done on chronic (or coping) strategies (Pickering and Pottinger 1989; Iwama 1997) and acute (“flight or fright”) stress responses in fish (Pickering 1981; Barton and Iwama 1991; Wendelaar Bonga 1997; Barton 2002). Stress—a disruption of homeostatic equilibrium that induces a cascade of neural, physiological, and behavioral changes and energy reallocation (Wendelaar Bonga 1997)—can be brought about by stressors that are physical or chemical (see Figure 2). The range and complexity of stress responses have been described as occurring in three phases: primary, secondary, and tertiary. The primary phase is release of the stress hormones, corticosteroids, and catecholamines into the bloodstream. The secondary phase involves hormonal effects at a cellular level, including energy mobilization and reallocation, osmotic disturbance, alterations to cardiac output, and oxygen uptake and transfer. The tertiary phase extends beyond the cellular level to organismal responses, including inhibition of immune response, reproduction, and growth, as well as decreased swimming performance or predator avoidance (Barton 2002; Barton and Iwama 1991; Iwama et al. 1997; Pickering and Pottinger 1989; Shreck et al. 2001; Marine and Cech 2004).

Integrated stress responses are difficult to isolate. As a result, differences between acute and chronic responses are not always evident, thus inferring a gradient in stress responses. Sublethal stress is often experimentally measured at the tertiary stressor level, and can include short-term effects such as reduced growth followed by compensatory growth (Van Weerd and Komen 1997; Berneir and Peter 2001), or longer-term responses that can alter population dynamics, such as poor egg quality or even cessation of reproduction (Donaldson 1991; Brooks et al. 1997). Therefore, a stressor matrix should include detailed descriptions of indictors (e.g., cortisol concentrations or metabolism) to define how stressors and expected stress responses are weighted (scored). Such a matrix approach should also include potential sublethal effects for the ranges of weights (scores). Additionally, to the panel’s knowledge, many of the proposed stressors have not been measured on multiple scales (i.e., cellular through organismal level effects). Therefore, a description of how measures or weights were assigned based on relevant literature should be considered in the analysis.

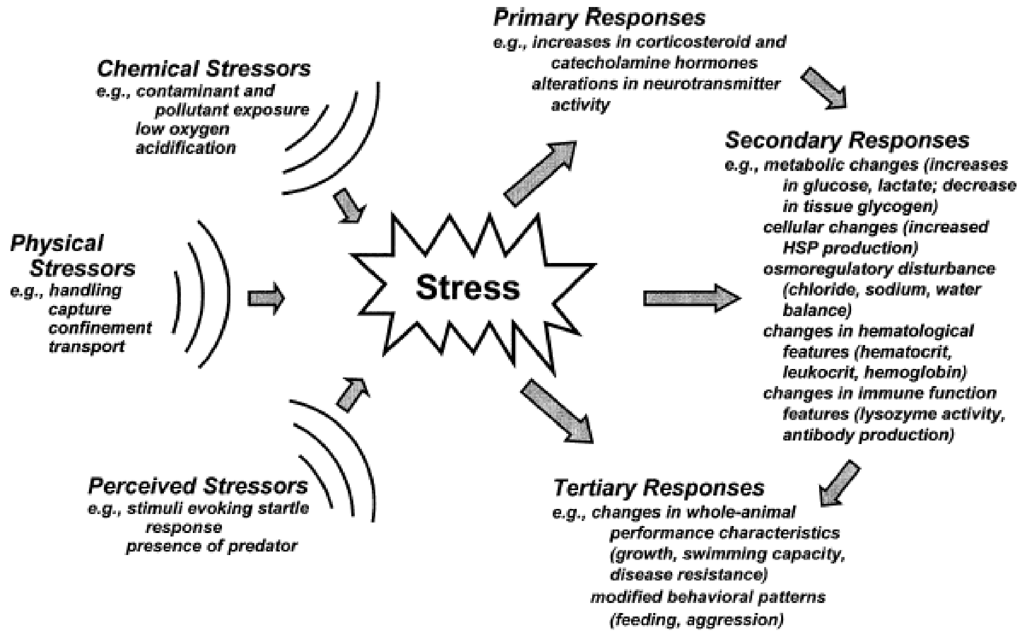

Figure 2. Physical, chemical, and other perceived stress can act of a fish response system to evoke physical and related effects, which are grouped as primary, secondary, and tertiary responses (Barton 2002)

Fixed Thermal Limits for Salmonids

Panel members were aware that many of the analyses use a target temperature of 56°F (13.3 °C) to indicate upper optimal (or suboptimal thermal limit) for certain salmonids. Use of any temperature threshold can lead to estimates of fish condition (i.e., normal or stressed). However, it must be recognized that this temperature metric is based on controlled laboratory results. Salmonids in the environment experience a range of natural and anthropogenic stressors that are not captured in laboratory experiments. Thus, 56°F is a reasonable indicator based on the available science, though further research is needed to understand the effects of variable temperature regimes using sensitive life stages. Understanding the sublethal effects associated with the upper and lower thermal tolerance limits for salmonids is essential for restoring and managing these fishes in such highly altered habitat.

Temperature in Salmon Mortality Models

Temperature is a centerpiece parameter in most salmon mortality models. As noted above, however, salmon are exposed to many natural and anthropogenic stressors that result in sublethal stress responses not commonly included in mortality models. The panel recommends that more detailed models, such as dynamic energy budget (DEB) models (see Figure 3), be considered to examine and predict energy allocation changes as fish experience sub-lethal stressors. These models use differential equations to describe the rates at which individual organisms assimilate and utilize energy from food for such essential processes as maintenance and such non-essential processes as growth and reproduction. Because these rates depend on the state of the organism (e.g., age, size, sex, and nutritional status) and environmental variables (e.g., food density and temperature), solutions of the DEB model equations represent the life history of individual organisms in a potentially variable environment. These models can be readily linked to hydrodynamic and stressor models that quantify energy allocation within an organism while incorporating realistic hydraulic regimes (Anderson et al. 2006). Additional applicable details about DEB models can be found in Kooijman (2004) and Sousa (2006).

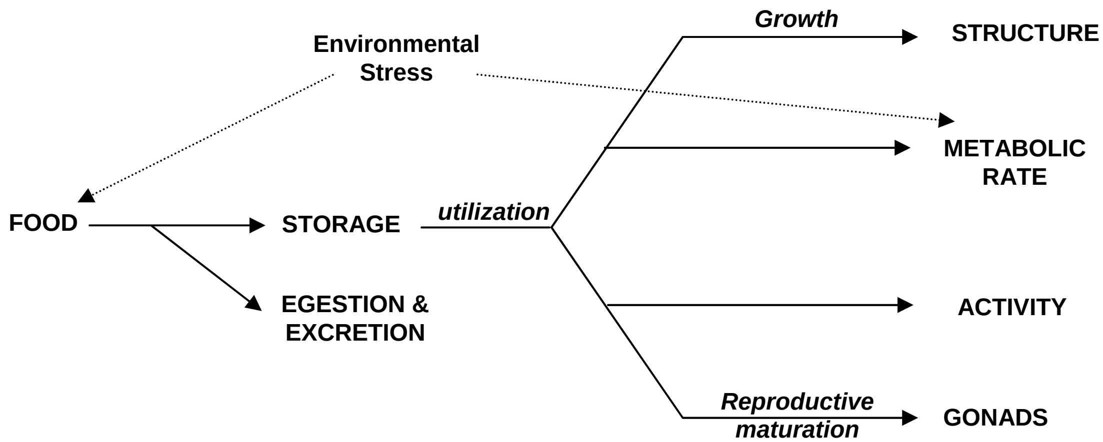

Figure 3. An example Dynamic Energy Budget (DEB) model (modified from Nisbet et al. 2000). An organism ingests food at a rate dependent on its size and the food density. Energy is extracted from food and added to the reserves. The rate at which energy becomes available to the organism depends on its size and stored energy density. Somatic maintenance has absolute priority for energy. Available energy is allocated to somatic maintenance and growth combined, while the remaining energy is allocated to either maturation or to reproduction and maturity maintenance. The organism may reproduce, provided that energy made available exceeds the requirements for somatic and maturity maintenance.

Comment 10: The panel recommends that NMFS and Reclamation coordinate management and monitoring efforts so all appropriate spatial and temporal scales are considered.

It appears that the expectations of NMFS for site-specific and temporal-specific project effects (e.g., water temperature, flow, and geomorphic effects on physical habitat) are inconsistent with the Reclamation's current models and operational plans. Operational impacts on physical and biological conditions must be assessed at spatial and temporal scales appropriate for focal species (and for the focal life stages). NMFS has developed a matrix approach to recovery planning that requires a range of temporal and spatial scale information that is not supported by existing data and models. Recovery planning should also consider a modeling approach that can accommodate estimates of uncertainty for project impacts.

The panel recommends that the various parties coordinate efforts so that all appropriate spatial and temporal scales are considered. This requires an integrated suite of analytical/modeling approaches to consider different resolutions for different processes.

Operations and Planning

Comment 11: The panel recommends that current climate change studies by the CASCADE program and the Desert Research Institute should be reviewed and considered for the BA.

California's climate is expected to change considerably during the next 50 years, presenting new challenges to native fishes and the management of water resources (Cayan et al. 2008; Milly et al. 2008). Climate models broadly agree that California's summer average temperatures will warm by 1.6 to 6.4^{o}C in this century, depending on the model and the scenario describing future greenhouse gas emissions (Cayan et al., 2008). Models do not agree regarding changes in total precipitation, but a warmer climate will increase the proportion of precipitation falling as rain and hasten the timing of snowmelt, causing hydrographs to peak earlier in the year and reducing summertime base flows. It is also likely that both droughts and floods will be more frequent and more severe.

Chinook salmon and steelhead are at the southern limit of their global ranges in California, and these range limits are determined largely by hydrographic and water temperature conditions. In particular, spring-run and winter-run Chinook salmon and steelhead must spend a portion of their life in freshwater during summer months, and warming conditions will likely have significant negative impacts on the fitness of these stocks, given that access to natural thermal refugia is blocked by impassable dams. Without access to these natural refugia, tailwater areas below dams will be critical to the survival of many populations (e.g., winter-run Chinook salmon).

Climate-driven changes to hydrographs will also challenge water resource managers. More rainfall will potentially make flood control more difficult, and reduced snowpack may effectively reduce water storage. In fact, rules for operating reservoirs will almost certainly require modification to adapt to such changes. In combination, these changes will make managing cold water pools in reservoirs more difficult. Furthermore, with the potential for more frequent, longer-lasting, and more severe droughts, conflict among various demands on California's water system will likely intensify (Knowles and Cayan 2002; Medellin-Azuara et al. 2008).

As a result of these conditions, historical data will prove less reliable for the purposes of calibrating models or projecting future conditions. The expansion of current monitoring programs is therefore prudent, particularly when coupled with adaptive management principles and the ability to make decisions based on near real-time data streams. Facilitated by new technologies, this more detailed monitoring will help ensure that ecological objectives are met while conserving cooler water for later in the season or increasing the potential for carry-over during droughts. The panel recommends that current climate change studies by the CASCADE program and the Desert Research Institute should be reviewed and considered for the BA.

These various considerations associated with climate change raise the following critical questions, which should be evaluated as part of any plans for operating California's water infrastructure with respect to salmonid populations:

- How much warming can salmonid populations withstand in their current habitats?
- Will reservoir tailwater conditions provide sufficient thermal refugia for salmonids?
- Can access be provided to upstream and/or floodplain natural thermal refugia?
- How will water storage and conveyance systems be operated when currently uncommon or unprecedented conditions occur more frequently?
- Will salmonid populations be viable under such management regimes?

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Appendix A: Materials Provided for Workshop

BA-BO Review Process2-nmfs: OCAP BA/BO PEER REVIEW PROCESS STATUS REPORT FOR 5 AGENCY. DRAFT 2/25/08

BDMFTempReview: Deas, M.L., and C.L. Lowney. 2000. *Water Temperature Modeling Review – Central Valley*. Prepared for the Bay Delta Modeling Forum. September.

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McMahon CIE Salmon review report - January 18, 2006: McMahon, T.E. _____. CIE REVIEW OF NOAA-FISHERIES BIOLOGICAL OPINION ON EFFECTS OF PROPOSED CENTRAL VALLEY PROJECT CHANGES ON LISTED FISH SPECIES.

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OCAP CALFED Review Final1: Lichatowich, J.A., J. Anderson, M. Deas, A. Giorgi, K. Rose, and J. Williams. 2005. *Review of the Biological Opinion of the Long-Term Central Valley Project and State Water Project Operations Criteria and Plan*. A Report of the Technical Review Panel. Prepared for Johnnie Moore, California Bay-Delta Authority. December.

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OCAPScenariosRationale_Brekke_080318: Brekki, L. 2008. "Central Valley Project Operations Criteria and Plan (OCAP) Biological Assessment: Treatment of Potential Climate Change Effects on future Runoff and Reservoir Operations (Sensitivity Analysis)" [Powerpoint]. February 29.

Sac R Decision.tree.3_25_05: Decision Criteria for Sacramento River Water Temperature Management (USBR).

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TempReview: Myrick, C.A., and J.J. Cech. 2001. *Temperature Effects on Chinook Salmon and Steelhead: a Review Focusing on California's Central Valley Populations*. Prepared for the Bay Delta Modeling Forum.

Appendix B: Workshop Presentations

Windham and Ellrott - NMFS Central Valley Salmonid Recovery Plan Threats Assessment and Temperature Information

Oppenheim - Salmonid Temperature Criteria and Management Strategy for Upper Sacramento River

Sandberg - SWRCB WRO 90-05 - Reclamation Process for Upper Sacramento River Water Temperature Control

Yaworsky - Operational and Temperature Modeling Tools Used on the Upper Sacramento River

Burke - Historical Temperature Management in the Upper Sacramento River - What can be learned from looking at the data?

Parker - Temperature Modeling to Support TMDL Development for the Klamath and Eel Rivers

Danner - A Remote Sensing and Climate Based CVP Temperature Model

Cavallo - IOS Modeling Tool for Winter Run and Operational Scenarios

All presentations are also available at:
http://www.science.calwater.ca.gov/events/workshops/workshop_tmm.html